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# ARKTOS: A Knowledge-Based Sea Ice Classification System

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The ARKTOS (Advanced Reasoning using Knowledge for Typing of Sea Ice) system is a sea ice classification system that incorporates image processing and Artificial Intelligence (AI) to analyze RADARSAT Synthetic Aperture Radar (SAR) images. As shown in Figure 1, ARKTOS first segments the input image using Watershed region growing technique based on image gradients, and subsequently merges regions based on area, average intensity, and strength of common boundaries. ARKTOS then computes attributes for each contiguous region (henceforth, feature) such as area, perimeter, average intensity, and circularity. Given these measurements, facts regarding each feature are formed by quantizing the values into symbols. For example, if the feature's average intensity is less than 50.0, then intensity (feature) = black. The decision points (or thresholds) were determined and refined via visual inspection of features. Next, during the classification phase, the Dempster-Shafer rule-base engine reads the facts and matches rules by looking for satisfied conditions. After matched rules are fired, the engine combines the evidence and gives the belief and plausibility values for a feature to be in one of the four ice classes. Finally, ARKTOS assigns the feature the ice class with the highest product of the plausibility and belief values. To facilitate the refinement process, we have included GUI modules. ARKTOS generates data for each feature such as boundary and shape information so that upon clicking on a feature, that information will be displayed. This allows human experts to conveniently evaluate the results. Once ARKTOS has stabilized, this modification accessory will be phased out and discarded.

We use the Dempster-Shafer belief system as the engine to manipulate sea ice knowledge because of its capability in considering both the lack and the existence of evidential facts for classification. It provides a logical set of combination rules to consider various pieces of evidence consistently.

Since ARKTOS is a knowledge-based system, knowledge acquisition and qualification is essential throughout the design and refinement process. Initially, we acquired knowledge from sea ice experts through interview sessions using different strategies such as protocol, blind test, and cross-reference. Each session was recorded and later transcribed with references to corresponding images and ice features. Following the acquisition stage was the qualification process. This was conducted to discard erroneous observations, reconcile similar assertions, and resolve conflicting analyses. This stage gave birth to the list of attributes that are currently computed in ARKTOS.

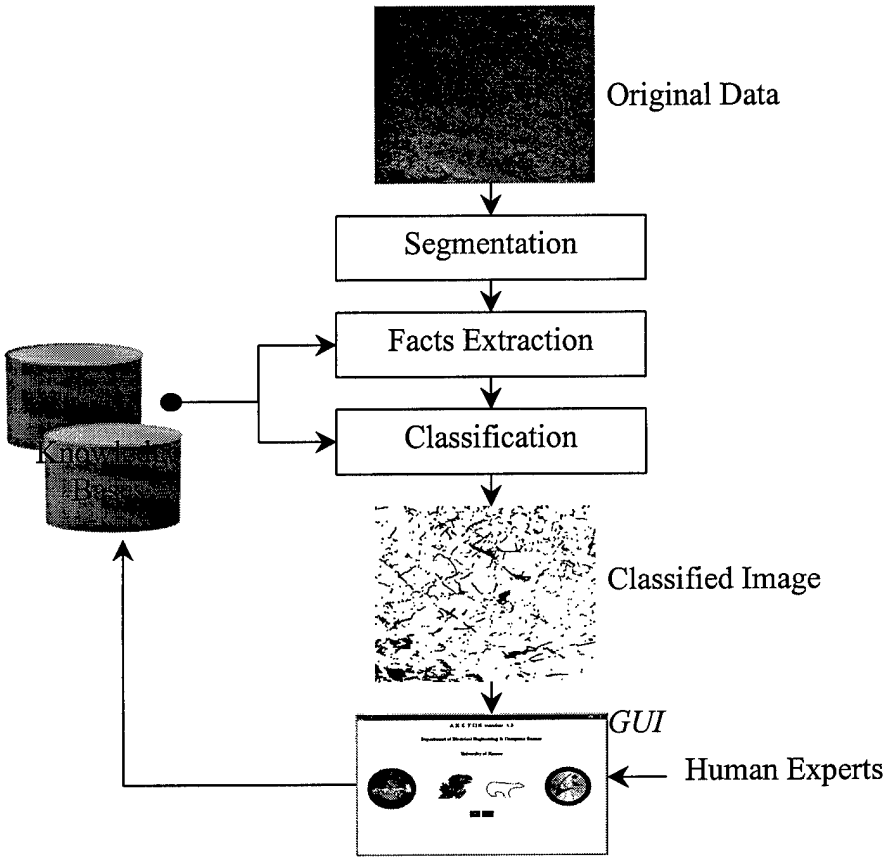


**Figure 1** Block diagram of ARKTOS.

Some attributes can be extracted directly from the ancillary file that accompanies each image; most are converted from high-level semantic entities to measurable descriptors. We accomplish the conversion by modeling the sea ice domain: we view each feature and declare its characteristics, and then compare them to the actual measured values. After performing this visual evaluation on a substantial number of features, decision points along each attribute's range of values can be established for quantization. There have been cases where consistent thresholds could not be identified that we have had to re-design the implementation of the attributes.

Because it is critical to have accurate knowledge content in an expert system, ARKTOS has been designed to support knowledge refinement. We have implemented a JAVA-based GUI that allows expert users to visually evaluate the classification results. The GUI displays the original, segmented, and classified images. It allows the experts to click on any feature to see the attribute and actual measurement values of the feature, the ancillary information about the image, the rules that fired for the feature, and its final classification. Thus, if the highlighted feature is incorrectly classified, the experts can identify the faulty component(s) in the reasoning chain, which can be the attributes, the decision points, or the rules. In addition, we have implemented our Dempster-Shafer rule-base engine so that the rules and decision points can be edited by the experts without further compilations, affording them an instantaneous view of the effects of the modifications they have made. Figure 2 shows the functionality and system flow of the GUI module of ARKTOS.

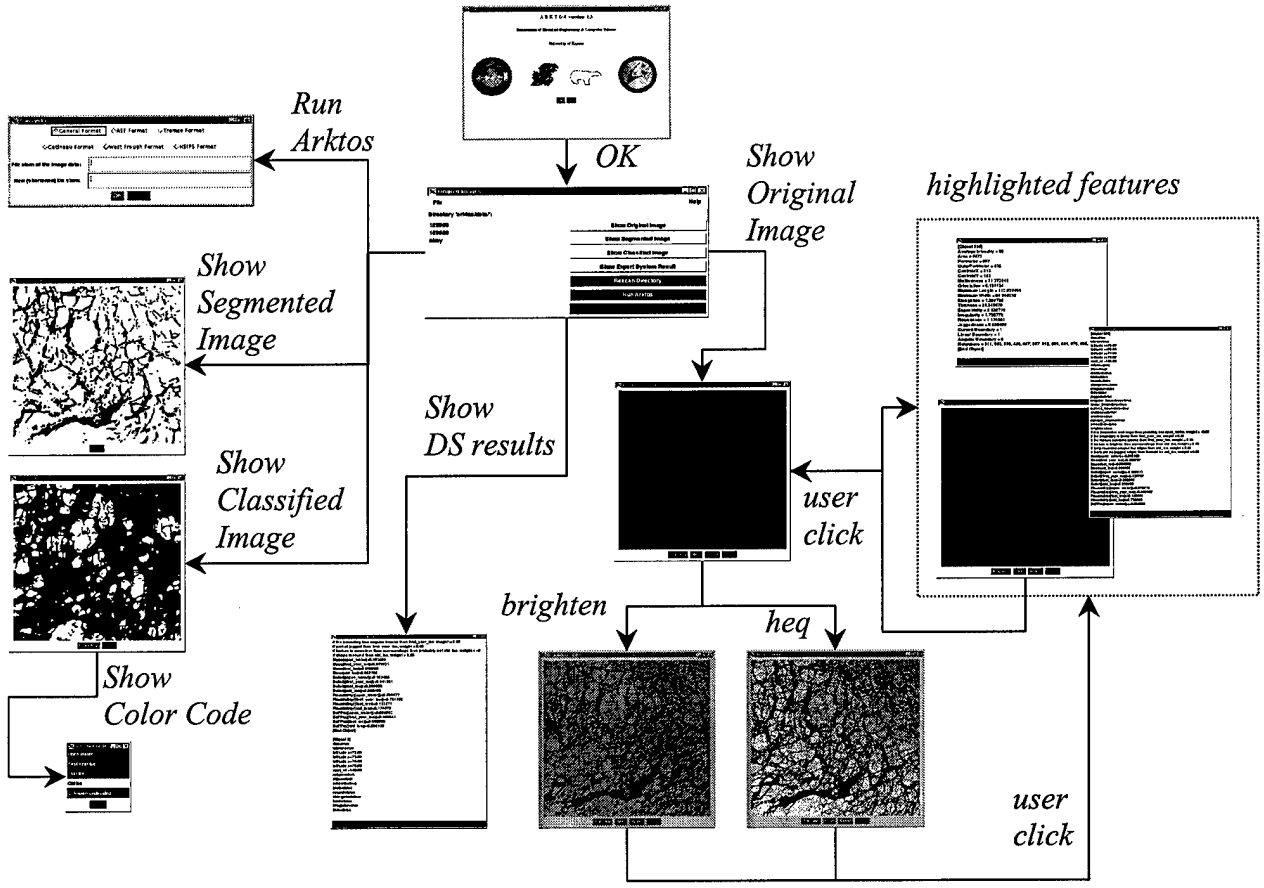


**Figure 2** System flow of the GUI module of ARKTOS.

Figure 3 shows one classification result of ARKTOS based on the current knowledge base. The original image is a RADARSAT image acquired on December 28, 1997 at 78.73°N, 117.86°W. It consists of mostly old ice, interspersed with broken regions of first year and open water/new ice. The classified image is color coded as the following: white for old ice, red for first year ice, green for fast ice, blue for open water/new ice, and black for unknown. As we can see, the image is classified correctly for more than 80% of its coverage.

In conclusion, we have described the ARKTOS knowledge-based sea ice classification system. ARKTOS incorporates AI technologies in knowledge acquisition and representation. It also employs a Dempster-Shafer belief system to handle evidence in its reasoning process. The infrastructure of ARKTOS is supported by image processing methodologies such as Watershed segmentation and other geometric and intrinsic attribute computations. The ARKTOS project also suggests how a knowledge-based system should be designed and refined—with an acquisition-design-refinement cycle that is facilitated by a GUI module to allow expert users to improve the knowledge base via visual inspection. Currently, ARKTOS is undergoing a productive and steadily converging refinement process at the National Ice Center (NIC) and the Naval Research Laboratory

(NRL). We are also working at ingesting other information sources such as climatological data, ice charts, and SSM/I data.

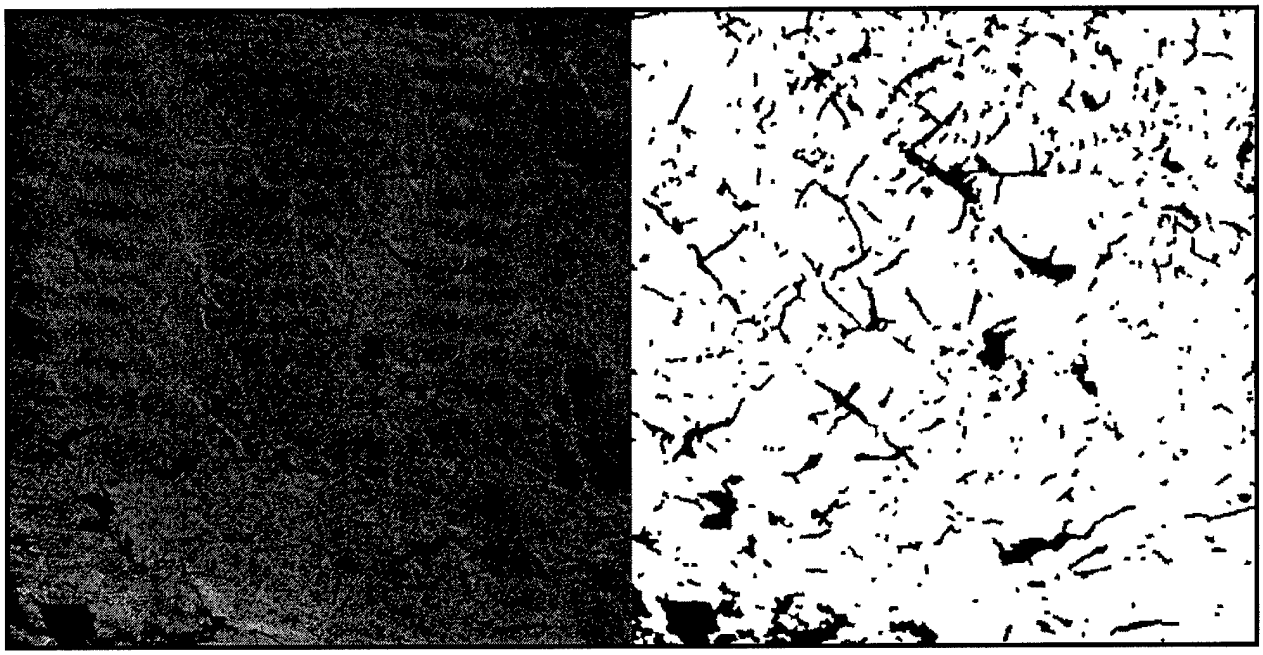

**Figure 3** An example of the classification results of ARKTOS.